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Reports of the Department of Geodetic Science

Report No. 169

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AN INVESTIGATION INTO SOME PROBLEMS IN ANALYTICAL PROCESSING OF LUNAR ORBITER PHOTOGRAPHY

by

Sanjib K. Ghosh
and
Sebastian Ekenobi

Prepared for

National Aeronautics and Space Administration
Office of Scientific and Technical Information (Code U.S.)
Washington, D.C. 20546

Grant No. NGR 36-008-125
OSURF Project No. 2810

Final Report

The Ohio State University
Research Foundation
Columbus, Ohio 43212

February 1972

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Prepared by: Dr. Sanjib K. Ghosh, Associate Professor
and
Mr. Sebastian Ekenobi, Graduate Research Associate

Submitted by: Department of Geodetic Science
The Ohio State University

Dr. Sanjib K. Ghosh
Associate Professor
Research Supervisor

Date: February 1972

FOREWORD

This project with NASA Grant No. NGR36-008-125, which is a part of the research program at NASA'S Manned spacecraft Center, Houston, Texas; was administered by NASA, Washington, D. C. with Mr. Joseph T. Davis as the grants officer and Mr. John P. Simpson as the NASA negotiator. Mr. Robert Hill acted as the Technical monitor.

This report covers research performed by Dr. Peter J. Morgan, Mr. Sebastian Ekenobi, Research Associates, Mrs. Guytanna Swisher, Research Aide and Dr. Sanjib K. Ghosh, Research Supervisor.

Support for this work in the form of computer facilities was made available by the Instructional and Research Computer Center of the Ohio State University (Dr. Roy F. Reeves, Director).

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1. INTRODUCTION

This work is a continuation of the research as reported in the Interim Report prepared by Morgan entitled "An Investigation Into Some Problems of Lunar Orbiter Photography System" [1] (being Report No. 162 of the Department of Geodetic Science, The Ohio State University).

Problems arise when non-metric cameras are used for metric work. The previous (interim) report involved the use of fictitious data to investigate into:

(a) the effect of image motion and image motion compensation on the location of the principal point.

(b) the possibility of determining the corrections to the calibrated values of the coordinates (defining the location of the principal point) in order to correct for the image motion compensation.

(c) the effect of the focal plane shutter on the distortion and interior geometry; and

(d) whether a lack of calibration information could be overcome by dynamic calibration procedures incorporated in the photographic mission.

The objective of the present work was to use real data to confirm the workability of the mathematical model and the validity of the conclusions presented in the Interim Report. The investigations involved the use of the IBM 360/75 computer system facilities available on the Ohio State University campus.

2. THE STUDIES AND THE NUMERICAL TESTS

The work can briefly be described as an adjustment problem, involving multi-photo and ground point parameters, in which the coordinates of the image points, the photostations and the object space points are very ill-defined. The mathematical model consisted of the well-known collinearity condition equations, which were augmented to include a three-dimensional camera-platform velocity and also the rates of change of the three rotation elements. By adding these six to the translational and rotational elements of exterior orientation and the coordinates of the principal point, there are in all fourteen unknown parameters for each photostation. A requirement for this set-up was the exposure epoch, Δt, which was associated with, and had a different value for each image point. Depending on the location of an image point on the format, Δt was calcuted from the slit velocity. Concerning this situation, it was expressed in [1] (page 3): "Unfortunately, these gains in generality have been accompanied by increased complexity of the model and consequently possible computational instability problems".

Before starting work, the researchers (a) checked the already developed computer program (which they had to work with) for purely programming errors, (b) prepared a flow chart for the program (see Appendix I), as it was deemed necessary in order to present a complete picture and to have an understanding of the program, (c) drew up, for the interest of the programmer, an extensive explanation to the handling of the various matrices.

As described in the Interim Report, extensive numerical tests were performed with fictitious data on the computer program and had produced encouraging results, (page 67 [1]). "Model testing", as reported in [1] (page 54) "is not complete without real data tests, even though tremendous insight and understanding may be gained when simulated data are used", although, to quote this Interim Report,

"----there is always a small probability that the simulated data conform to the proposed model, whereas the real data are not represented by the proposed model".

2.1 WORK WITH REAL DATA

Numerical tests with real data were performed paying due attention to the recommendations as put in the interim report. The recommendations considered significantly important were:

(a) "----the parameter recovered would be more exact if approximate values were first obtained by single photo space resection procedures", (page 88).

(b)----a small real data test (should) be performed so that the validity of the proposed model and the conclusions are confirmed", (page 89).

(c)----weights should accurately reflect the observational precision", (page 82).

Real data available from NASA [3] included image coordinates, camera station parameters, geographic coordinates of a good number of ground points, and the camera slit velocity. Fifteen points, common to two photos were chosen. (Nos. 97 and 102)

With the availability of the geographic coordinates of the points, the estimation of initial approximations of most of the parameters was possible, yet it was not considered out of the way trying some other computations, three of which are:

(i) pure aerial strip triangulation (in this case only two photos were involved).

(ii) image-to-object direct transformation.

(iii) space resection for exterior orientation elements using as knowns the (X, Y, Z) coordinates evaluated from the geographic coordinates.

None of the attempts, however, produced results that could be judged better than what were already available.

The initial approximations for the principal point (x_o, y_o) were taken from the calibration report [2], the photostation coordinates and attitudes (X_o, Y_o, Z_o, ω, ϕ, κ) were taken from data supplied by NASA [3], the photostation velocity components and the rates of change of the attitudes (V_x, V_y, V_z, $\dot{\omega}$, $\dot{\phi}$, $\dot{\kappa}$) were estimated following recommendations in the Interim Report (see [1], pp 5 & 83); ground coordinates (X, Y, Z) were estimated from the given selenodetic coordinates (latitude, longitude, and elevation) of each point. The different weights given to the parameters were as suggested in the Interim Report.

2.2 THE RESULTS

The results were not good. The incremental corrections showed an obvious divergence. Concerning convergence and divergence, it was reported in the Interim Report:

(i) "It was found that the initial approximations to the unknown parameters had to be reasonable, otherwise no convergence occurred due to the non-linearity of the model". (page 68)

(ii) "----it was determined that a practical limit of three iterations was necessary for the moderately perturbed test data. As the perturbations became large, it was necessary to complete more iterations to achieve the same level of precision". (page 82)

(iii) "The weights associated with the survey stations did not truly represent the situation, since no random errors were impressed upon these values. Thus, the convergence rate was slowed down due to this incorrect weight", (page 82).

(iv) "----it was decided to present instead the corrections to be applied to the approximate values on completion of the first iteration. Thus the table illustrates, in a limited manner, the convergence characteristics of the solution", (page 85).

The last statement (iv) seemed to deserve the most attention. The convergence characteristics of the solution were not clear from the table referred to (Table 9, page 83). Hence it was decided to rerun simulated data (as reported in [1] for 9 iterations. In Appendix III, the word "RESIDUALS" should read incremental corrections, and all angular parameters are in radians. The first, second, third, and ninth iterations are shown.

These computer outputs show an obvious divergence. Investigations with fictitious data had therefore failed.

This failure was found to be due to certain complications in the partial differentials subroutine. This subroutine, involving 14 parameters per photograph, was the major and the most complicated part of the whole work. While attempt is still being made to resolve the complications, with a view to submitting this report in time, a similar subroutine for the partials of only 6 parameters per photograph has been substituted for the real data.

The condition for termination of iterations was that the correction for each of the three rotational elements (κ, ϕ and ω) must be less than or equal to 10^{-6} radian. This occurred after the eighth iteration. The first and the last iterations are presented in Appendix III from which the convergence characteristics can be examined.

2.3 WEIGHTING CRITERIA

Optimum weighting criteria have not been established. It was, however, found that weighting has a strong influence on the rate of convergence, the final results and the computer time.

Table 2.1 shows, for this adjustment, the different standard deviations associated with the different parameters.

TABLE 2.1

Standard Deviations of
the Real Data Parameters

Image coordinates:	x, y	± 150 μm
Ground coordinates:	X, Y, Z	± 200 m
Photo station:	X_o, Y_o, Z_o	± 40 m
	κ, φ, ω	± 60' minutes

3. CONCLUSIONS

The failure of work with fictitious data destroys the very basis of the objectives of this work with real data. It is regretted that this failure was discovered only too late. However, the results of the adjustments involving 6 photo parameters are considered encouraging. There is no doubt that the addition of the remaining 8 photo parameters will improve the pattern and yield the expected results. It goes without saying therefore, that the authors believe in the soundness of the augmentation of the collinearity condition equations to handle the adjustment problems of the Lunar Orbiter Photography data.

It might be added that the Contractors and/or Scientists who handle estimation of the photographic image coordinates and/or do the preliminary adjustments, should provide accuracy estimates (which of course should be better than our own imaginings) with which the various parameters of the data could be associated.

BIBLIOGRAPHY

1. Morgan, P. J., An Investigation Into Some Problems of Lunar Orbiter Photography System; Report No. 162, Department of Geodetic Science, The Ohio State University, August, 1971.

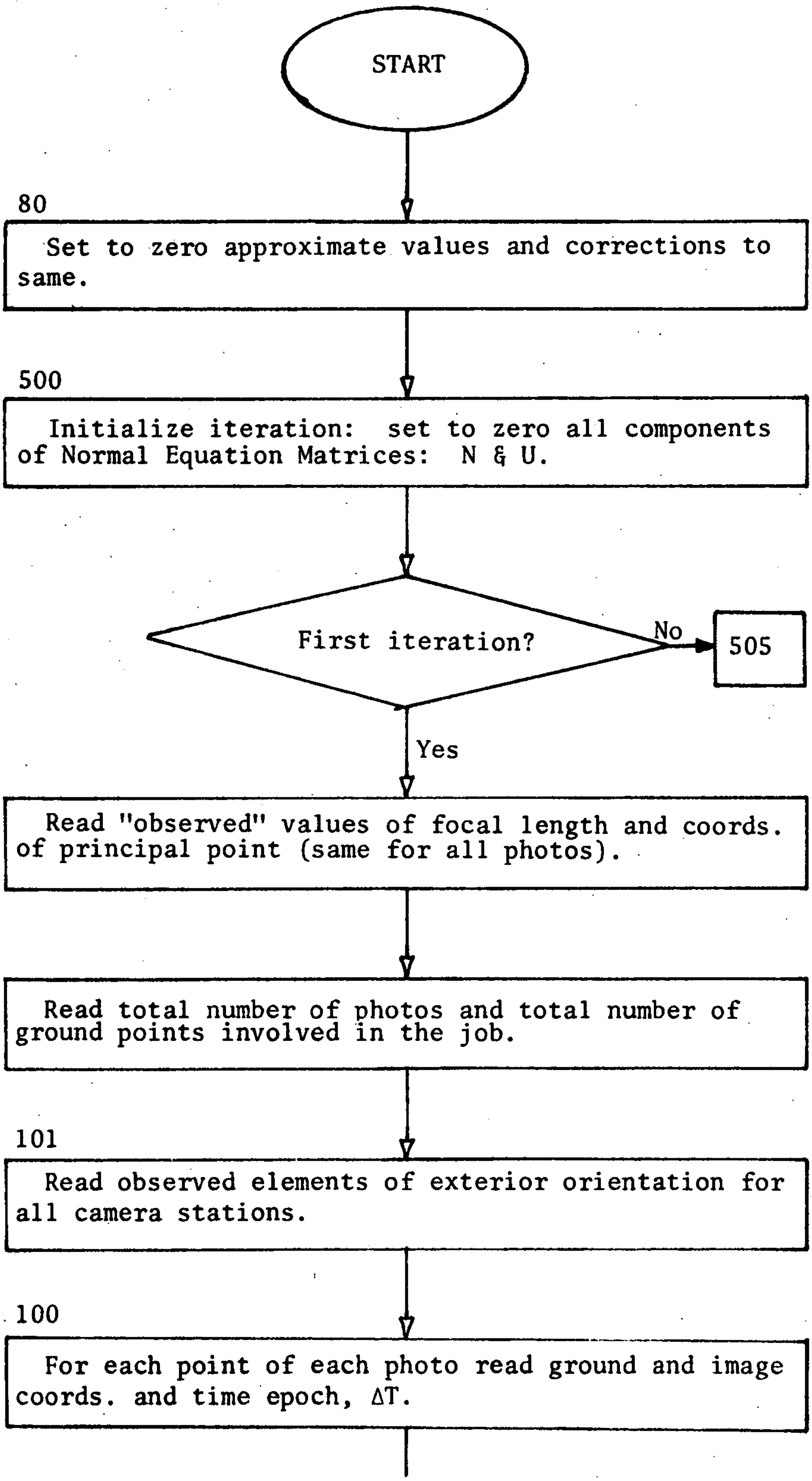
2. United States Air Force Aeronautical Chart and Information Center, Lunar-Planetary Branch Cartography Division; Lunar Orbiters IV and V Camera Calibration Report, January, 1968.

3. National Aeronautics and Space Administration, Manned Space-Craft Center, Lunar Orbiter IV Photography Data; (exposure station parameters, photographic plate measurements and selenographic coordinates) - Communications from Mr. Robert Hill, NASA, MSC, May 24, 1971.

APPENDIX I

FLOW CHART OF THE FORTRAN PROGRAM

The numbers on top of some of the blocks are the statement numbers of their first Fortran statements.


START
80
Set to zero approximate values and corrections to same.
500
Initialize iteration: set to zero all components of Normal Equation Matrices: N & U.
First iteration?
No
505
Yes
Read "observed" values of focal length and coords. of principal point (same for all photos).
Read total number of photos and total number of ground points involved in the job.
101
Read observed elements of exterior orientation for all camera stations.
100
For each point of each photo read ground and image coords. and time epoch, ΔT.

102

Read Approximate data: number equals number of unknowns: photo principal points, elements of exterior orientation of all camera stations and their velocities, and ground coordinates.

↓

Read given ground coordinates.

↓

Form the P_α-matrix to be used for differentiation by skew symmetric method.

↓

505

Treat the photos one at a time, starting with the first, as follows:

↓

91

Set to zero the matrices A, AT, B, BT, ATA, ATB, BTA (=transpose of ATB), BTB, L, & BTL.

↓

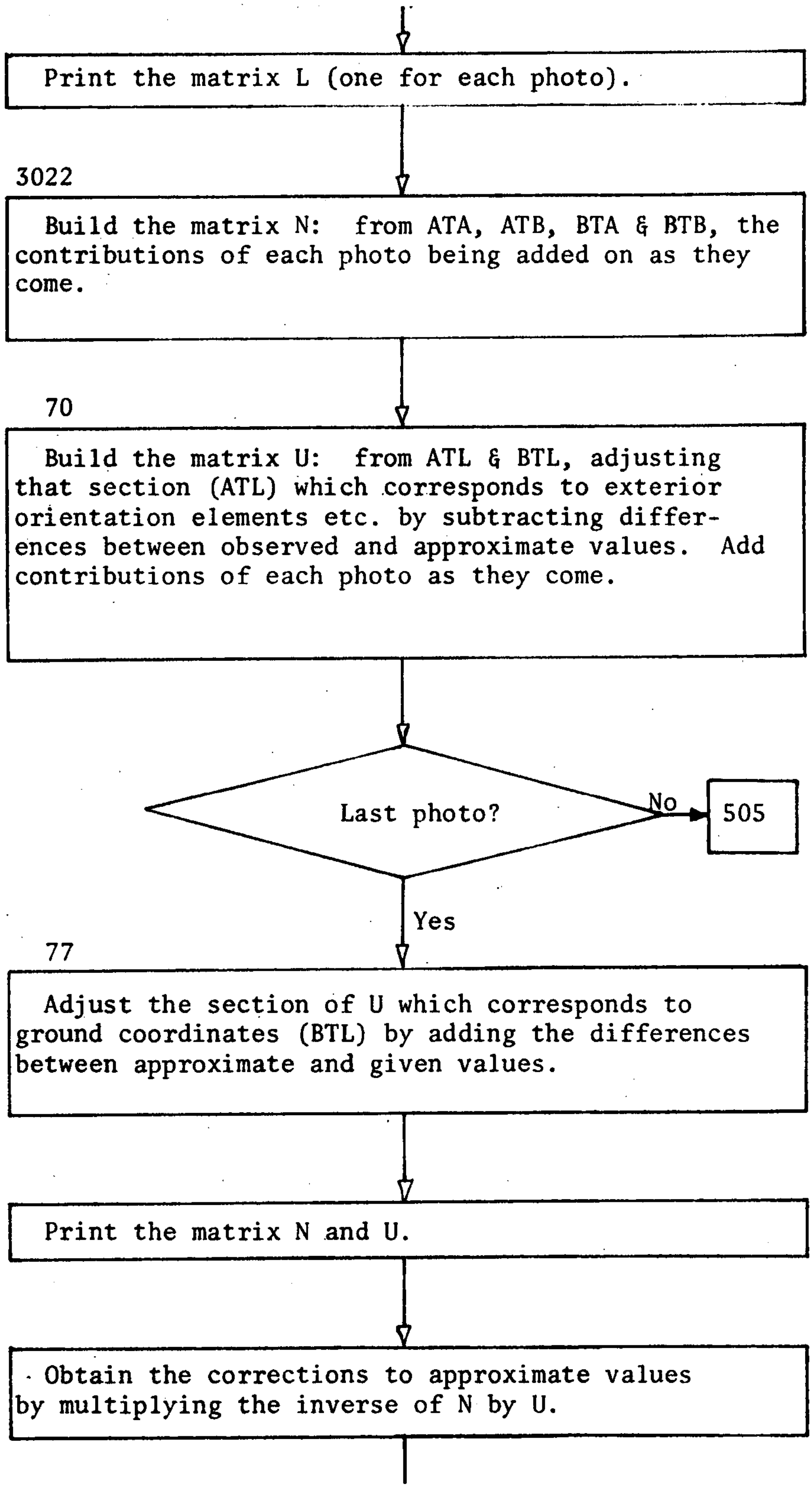
3011

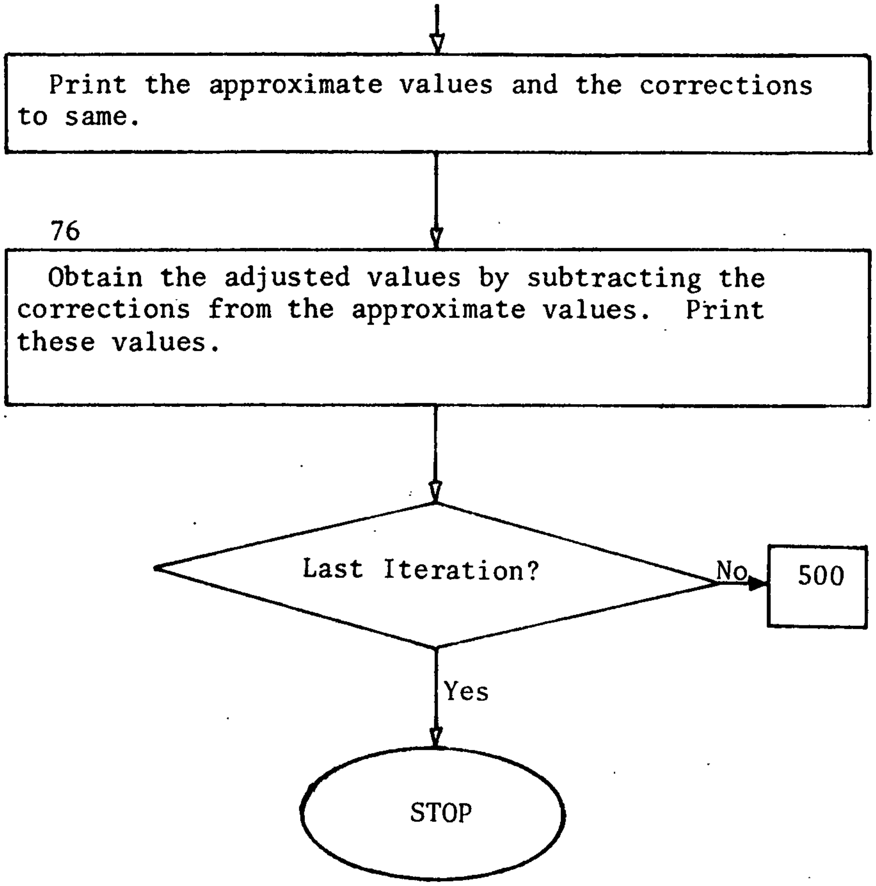
For each point of each photo, form the augmented rotation matrix, differentiate same, and then form and store the contributions to the matrices A, B & L (Interim Report, P. 15 and Appendix F). Further explanation follows the Flow Chart

↓

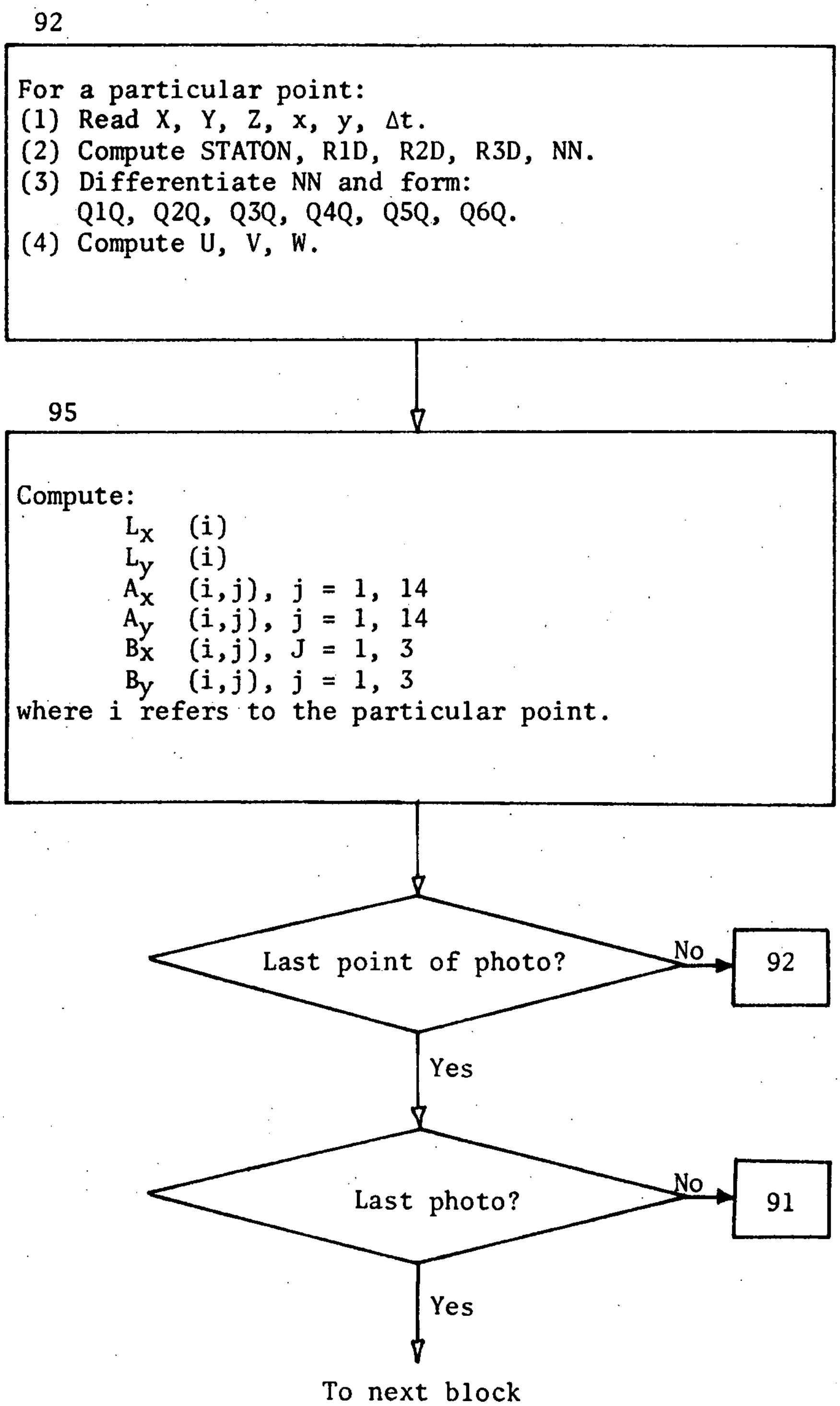
151

Compute the components of the Matrices (N & U) of the Normal Equations, namely ATA, ATB, BTA, BTB, ATL, & BTL.


Print the matrix L (one for each photo).
3022
Build the matrix N: from ATA, ATB, BTA & BTB, the contributions of each photo being added on as they come.
70
Build the matrix U: from ATL & BTL, adjusting that section (ATL) which corresponds to exterior orientation elements etc. by subtracting differences between observed and approximate values. Add contributions of each photo as they come.
Last photo?
No
505
Yes
77
Adjust the section of U which corresponds to ground coordinates (BTL) by adding the differences between approximate and given values.
Print the matrix N and U.
Obtain the corrections to approximate values by multiplying the inverse of N by U.


Print the approximate values and the corrections to same.
76
Obtain the adjusted values by subtracting the corrections from the approximate values. Print these values.
Last Iteration?
No
500
Yes
STOP

As it is deemed necessary for a clearer understanding, an expanded flow chart of block No. 3011 is given below:



Explanation of Block No. 3011

$\begin{bmatrix} x \\ y \end{bmatrix}$ Image coordinates of each point.

$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$ Ground coordinates of each point.

$\begin{bmatrix} x_o \\ y_o \end{bmatrix}$ Principal point coordinates.

$\begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix}$ Photostation coordinates.

$\begin{bmatrix} \omega \\ \phi \\ \kappa \end{bmatrix}$ Rotation elements of camera.

$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}$ Velocity components of photostation.

$\begin{bmatrix} \dot{\omega} \\ \dot{\phi} \\ \dot{\kappa} \end{bmatrix}$ Rates of change of rotation elements.

Δt For each point, the time lapse from the epoch ($\Delta t_o = 0$) to the moment under consideration.

$$P1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & -1 & 0 \end{bmatrix}$$

$$P2 = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

$$P3 = \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

P1, P2, P3 are constants, referred to as P_α in the Interim Report, P. 95.

$$R1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix}$$

$$R2 = \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix}$$

$$R3 = \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Values of R1, R2, R3 respectively are the same for all points in the same photo.

Each point in each photo is treated as follows:

$$R1D = \Delta t \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\dot{\omega} & \sin\dot{\omega} \\ 0 & -\sin\dot{\omega} & \cos\dot{\omega} \end{bmatrix}$$

$$R2D = \Delta t \begin{bmatrix} \cos\dot{\phi} & 0 & -\sin\dot{\phi} \\ 0 & 1 & 0 \\ \sin\dot{\phi} & 0 & \cos\dot{\phi} \end{bmatrix}$$

$$R3D = \Delta t \begin{bmatrix} \cos\dot{\kappa} & \sin\dot{\kappa} & 0 \\ -\sin\dot{\kappa} & \cos\dot{\kappa} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$NN = (R3\ R3D)\ (R2\ R2D)(R1\ R1D)$$

$$STATON = \begin{bmatrix} X - X_o - V_x\Delta t \\ Y - Y_o - V_y\Delta t \\ Z - Z_o - V_z\Delta t \end{bmatrix}$$

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} NN \end{bmatrix} \begin{bmatrix} STATON \end{bmatrix}$$

$$\begin{bmatrix} Q1Q(1) \\ Q1Q(2) \\ Q1Q(3) \end{bmatrix} = (P3\ \ NN)\ (STATON) = \begin{bmatrix} \frac{\partial U}{\partial \kappa} \\ \frac{\partial V}{\partial \kappa} \\ \frac{\partial W}{\partial \kappa} \end{bmatrix}$$

$$\begin{bmatrix} Q2Q(1) \\ Q2Q(2) \\ Q2Q(3) \end{bmatrix} = (R3\ \ R3D\ \ P2\ \ R3D^T\ \ R3^T\ \ NN)\ (STATON) = \begin{bmatrix} \frac{\partial U}{\partial \phi} \\ \frac{\partial V}{\partial \phi} \\ \frac{\partial W}{\partial \phi} \end{bmatrix}$$

$$\begin{bmatrix} Q3Q(1) \\ Q3Q(2) \\ Q3Q(3) \end{bmatrix} = (NN\ \ R1D^T\ \ P1\ \ R1D)\ (STATON) = \begin{bmatrix} \frac{\partial U}{\partial \omega} \\ \frac{\partial V}{\partial \omega} \\ \frac{\partial W}{\partial \omega} \end{bmatrix}$$

$$\begin{bmatrix} Q4Q(1) \\ Q4Q(2) \\ Q4Q(3) \end{bmatrix} = (R3\ \ P3\ \ R3^T\ \ NN)(STATON)(\Delta t) = \begin{bmatrix} \frac{\partial U}{\partial \dot{\kappa}} \\ \frac{\partial V}{\partial \dot{\kappa}} \\ \frac{\partial W}{\partial \dot{\kappa}} \end{bmatrix}$$

$$\begin{bmatrix} Q5Q(1) \\ Q5Q(2) \\ Q5Q(3) \end{bmatrix} = (NN\ \ R1D^T\ \ R1^T\ \ P2\ \ R1\ \ R1D)(STATON)(\Delta t) = \begin{bmatrix} \frac{\partial U}{\partial \dot{\phi}} \\ \frac{\partial V}{\partial \dot{\phi}} \\ \frac{\partial W}{\partial \dot{\phi}} \end{bmatrix}$$

$$\begin{bmatrix} Q6Q(1) \\ Q6Q(2) \\ Q6Q(3) \end{bmatrix} = (NN\ P1)(STATON)(\Delta t) = \begin{bmatrix} \frac{\partial U}{\partial \dot{\omega}} \\ \frac{\partial V}{\partial \dot{\omega}} \\ \frac{\partial W}{\partial \dot{\omega}} \end{bmatrix}$$

$$L_x(i) = x + f\frac{U}{W} - x_o$$

$$L_y(i) = y + f\frac{V}{W} - y_o$$

(See also Table I.1 for the formation of coefficient matrices).

TABLE I.1

List of Coefficients

	$A_x(i,j)$	$A_y(i,j)$		$B_x(i,j)$	$B_y(i,j)$	
(i,1)	1	0				x_o
(i,2)	0	1				y_o
(i,3)	$-\frac{f}{W}(-n_{11}+n_{31}\frac{U}{W})$	$-\frac{f}{W}(-n_{21}+n_{31}\frac{V}{W})$	(i,1)	$-A_x(i,3)$	$-A_y(i,3)$	X_o
(i,4)	$-\frac{f}{W}(-n_{12}+n_{32}\frac{U}{W})$	$-\frac{f}{W}(-n_{22}+n_{32}\frac{V}{W})$	(i,2)	$-A_x(i,4)$	$-A_y(i,4)$	Y_o
(i,5)	$-\frac{f}{W}(-n_{13}+n_{33}\frac{U}{W})$	$-\frac{f}{W}(-n_{23}+n_{33}\frac{U}{W})$	(i,3)	$-A_x(i,5)$	$-A_y(i,5)$	Z_o
(i,6)	$-\frac{f}{W}(\frac{\partial U}{\partial \omega} - \frac{U}{W}\frac{\partial W}{\partial \omega})$	$-\frac{f}{W}(\frac{\partial V}{\partial \omega} - \frac{V}{W}\frac{\partial W}{\partial \omega})$				ω
(i,7)	$-\frac{f}{W}(\frac{\partial U}{\partial \phi} - \frac{U}{W}\frac{\partial W}{\partial \phi})$	$-\frac{f}{W}(\frac{\partial V}{\partial \phi} - \frac{V}{W}\frac{\partial W}{\partial \phi})$				ϕ
(i,8)	$-\frac{f}{W}(\frac{\partial U}{\partial \kappa} - \frac{U}{W}\frac{\partial W}{\partial \kappa})$	$-\frac{f}{W}(\frac{\partial V}{\partial \kappa} - \frac{V}{W}\frac{\partial W}{\partial \kappa})$				κ
(i,9)	$A_x(i,3)\cdot\Delta t$	$A_y(i,3)\cdot\Delta t$				V_x
(i,10)	$A_x(i,4)\cdot\Delta t$	$A_y(i,4)\cdot\Delta t$				V_y
(i,11)	$A_x(i,5)\cdot\Delta t$	$A_y(i,5)\cdot\Delta t$				V_z
(i,12)	$-\frac{f}{W}(\frac{\partial U}{\partial \dot{\omega}} - \frac{U}{W}\frac{\partial W}{\partial \dot{\omega}})$	$-\frac{f}{W}(\frac{\partial V}{\partial \dot{\omega}} - \frac{V}{W}\frac{\partial W}{\partial \dot{\omega}})$				$\dot{\omega}$
(i,13)	$-\frac{f}{W}(\frac{\partial U}{\partial \dot{\phi}} - \frac{U}{W}\frac{\partial W}{\partial \dot{\phi}})$	$-\frac{f}{W}(\frac{\partial V}{\partial \dot{\phi}} - \frac{V}{W}\frac{\partial W}{\partial \dot{\phi}})$				$\dot{\phi}$
(i,14)	$-\frac{f}{W}(\frac{\partial U}{\partial \dot{\kappa}} - \frac{U}{W}\frac{\partial W}{\partial \dot{\kappa}})$	$-\frac{f}{W}(\frac{\partial V}{\partial \dot{\kappa}} - \frac{V}{W}\frac{\partial W}{\partial \dot{\kappa}})$				$\dot{\kappa}$

Note: n = NN

i_{max} = no. of points in the photo.

j_{max} = 14.

For one photo the 3 matrices and their sizes are:

L_1 (2n x 1)

A_1 (2n x 14)

B_1 (2n x 3n)

where n is the number of points in the photo.

Each image point contributes 2 rows to each matrix, [that is L(2x1), A(2x14), B(2x3)]. B is a quasi-diagonal matrix.

The matrices N and U of the Normal Equations of the form,

$$NX + U = 0$$

where X represents 100 unknowns for the single model:

(i) 14 unknowns for each of the 2 photos,

(ii) 3 unknowns (X, Y, Z) for each of the 24 ground points.

THE MATRIX N
(100 x 100)

Photo 1 $ATA+P_2$ (14x14)		Photo 1 ATB (14x72)
	Photo 2 $ATA+P_2$ (14x14)	Photo 2 ATB (14x72)
Photo 1 BTA (72x14)	Photo 2 BTA (72x14)	Photo 1 & Photo 2 $BTB_1 + BTB_2 + P_3$ (72x72)

P_2 = weights of photo parameters
P_3 = weights of ground coordinates

THE MATRIX U
(100 x 1)

Photo 1 ATL (14x1)	-	Photo 1 $(XOBS - APPROX)P_2$
Photo 2 ATL (14x1)	-	Photo 2 $(XOBS - APPROX)P_2$
Photos 1 & 2 BTL_1 & BTL_2 (72x1)	+	Common Ground Coordinates $(APPROX - GIVEN)P_3$

APPENDIX II

FICTITIOUS DATA ADJUSTMENT RESULTS

THE APPROXIMATE VALUES BEFORE ADJUSTMENTS

PHOTO NO. 1

PRINCIPAL POINT:	X 0.200	Y 0.240	
PHOTOSTATION:	XO 4319900.000	YO -199990.000	ZO 921900.000
ROTATIONS:	OMEGA 0.175	PHI 1.396	KAPPA 0.0
PHOTOSTATION VELOCITIES:	VXO 90.000	VYO -95.000	VZO 1995.000
RATE OF CHANGE OF ROTATIONS:	D(OMEGA) 0.0	D(PHI) 0.0	D(KAPPA) 0.0

PHOTO NO. 2

PRINCIPAL POINT:	X 0.200	Y 0.240	
PHOTOSTATION:	XO 4319900.000	YO 199990.000	ZO 921900.000
ROTATIONS:	OMEGA 0.175	PHI 1.396	KAPPA 0.0
PHOTOSTATION VELOCITIES:	VXO 90.000	VYO 95.000	VZO 1995.000
RATE OF CHANGE OF ROTATIONS:	D(OMEGA) 0.0	D(PHI) 0.0	D(KAPPA) 0.0

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1	1731858.732	157282.163	52983.472
POINT NO. 2	1696658.215	129022.695	344261.000
POINT NO. 3	1717526.701	152552.616	230640.278
POINT NO. 4	1718497.813	170762.421	192384.634
POINT NO. 5	1618423.867	55728.424	642257.063

POINT NO.	6	1517350.604	28178.967	848152.132
POINT NO.	7	1493231.377	38796.594	886698.428
POINT NO.	8	1733280.268	34234.229	121499.117
POINT NO.	9	173405.954	74519.986	99356.793
POINT NO.	10	1712400.586	10315.770	305999.576
POINT NO.	11	1661907.762	-53730.538	514155.736
POINT NO.	12	1636806.111	-54107.677	589510.465
POINT NO.	13	1570652.229	-71572.639	735626.476
POINT NO.	14	1738061.981	11866.407	36054.608
POINT NO.	15	1717692.092	-34856.184	272356.670
POINT NO.	16	1678950.527	-56926.021	447380.931
POINT NO.	17	1724161.034	-73053.535	204030.334
POINT NO.	18	1716498.274	-91912.003	264732.061
POINT NO.	19	1625635.830	-128653.741	600053.878
POINT NO.	20	1525588.236	-170911.859	817126.435
POINT NO.	21	1735408.963	-79019.536	72490.268
POINT NO.	22	1726572.242	-106750.737	192865.928
POINT NO.	23	1695279.336	-140235.867	368728.193
POINT NO.	24	1680097.468	-146688.881	421533.646

NO. OF ITERATIONS = 1

PHOTO NO. 1

	X	Y	
PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.201	0.229	
RESIDUALS	-0.001	0.011	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319981.246	-200007.576	921927.526
RESIDUALS	-81.246	17.576	-27.526
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.175	1.396	0.000
RESIDUALS	0.000	0.000	-0.000
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	100.000	-100.000	2000.000
RESIDUALS	-10.000	5.000	-5.000
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	0.000	-0.000	-0.000
RESIDUALS	-0.000	0.000	0.000

PHOTO NO. 2

	X	Y	
PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.200	0.235	
RESIDUALS	-0.000	0.005	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319992.651	200001.350	921934.886
RESIDUALS	-92.651	-11.350	-34.886
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.175	1.396	0.000
RESIDUALS	-0.000	0.000	-0.000
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	100.000	100.000	2000.000
RESIDUALS	-10.000	-5.000	-5.000
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	0.000	-0.000	-0.000
RESIDUALS	-0.000	0.000	0.000

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1			
ADJUSTED VALUES	1731883.830	157297.320	52968.275
RESIDUALS	-25.099	-15.158	15.197
POINT NO. 2			
ADJUSTED VALUES	1696666.562	129033.918	344269.574
RESIDUALS	-8.347	-11.224	-8.575

NO. OF ITERATIONS = 2

PHOTO NO. 1

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.175	0.219	
RESIDUALS	0.025	0.011	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319958.282	-199985.347	921853.296
RESIDUALS	22.964	-22.229	74.230
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.175	1.396	-0.000
RESIDUALS	-0.000	0.000	0.000
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	99.995	-99.999	1999.999
RESIDUALS	0.005	-0.000	0.001
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-0.000	-0.000	-0.000
RESIDUALS	0.000	0.000	0.000

PHOTO NO. 2

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.173	0.227	
RESIDUALS	0.027	0.008	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319987.535	200035.401	921878.058
RESIDUALS	5.116	-34.051	56.828
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.175	1.396	0.000
RESIDUALS	0.000	0.000	-0.000
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	100.005	100.000	2000.002
RESIDUALS	-0.005	0.000	-0.001
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-0.000	-0.000	0.000
RESIDUALS	0.000	-0.000	-0.000

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1			
ADJUSTED VALUES	1731902.834	157314.869	52953.787
RESIDUALS	-19.003	-17.549	14.489
POINT NO. 2			
ADJUSTED VALUES	1696671.876	129045.081	344282.020
RESIDUALS	-5.314	-11.162	-12.446

NO. OF ITERATIONS = 3

PHOTO NO. 1

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.125	0.201	
RESIDUALS	0.051	0.018	

PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319910.177	-199945.282	921700.983
RESIDUALS	48.105	-40.064	152.313

ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.175	1.396	-0.000
RESIDUALS	-0.000	0.000	0.000

PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	99.975	-99.998	1999.995
RESIDUALS	0.020	-0.001	0.004

RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-0.001	-0.000	-0.000
RESIDUALS	0.000	0.000	0.000

PHOTO NO. 2

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	0.120	0.207	
RESIDUALS	0.053	0.019	

PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4319973.843	200108.543	921769.440
RESIDUALS	13.692	-73.142	108.618

ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.174	1.396	0.000
RESIDUALS	0.000	0.000	-0.000

PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	100.025	100.000	2000.005
RESIDUALS	-0.020	0.000	-0.003

RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-0.000	-0.000	0.001
RESIDUALS	0.000	0.000	-0.001

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1			
ADJUSTED VALUES	1731961.400	157349.438	52935.020
RESIDUALS	-58.567	-34.568	18.766
POINT NO. 2			
ADJUSTED VALUES	1696687.063	129070.504	344311.239
RESIDUALS	-15.187	-25.423	-29.219

NO. OF ITERATIONS = 9

PHOTO NO. 1

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	-6.100	-50.921	
RESIDUALS	7.031	46.378	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4297353.050	-375875.940	881686.806
RESIDUALS	15076.742	147463.560	23096.054
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.140	1.347	0.031
RESIDUALS	0.070	0.023	-0.058
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	100.968	-100.636	1999.140
RESIDUALS	-10.372	0.915	-0.614
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-1.243	-0.129	-0.968
RESIDUALS	0.664	0.055	0.786

PHOTO NO. 2

PRINCIPAL POINT:	X	Y	
ADJUSTED VALUES	-14.318	-32.519	
RESIDUALS	11.400	24.976	
PHOTOSTATION:	XO	YO	ZO
ADJUSTED VALUES	4317505.692	88661.141	932835.997
RESIDUALS	-2844.088	107174.400	-2659.126
ROTATIONS:	OMEGA	PHI	KAPPA
ADJUSTED VALUES	0.190	1.351	-0.071
RESIDUALS	-0.044	0.020	0.091
PHOTOSTATION VELOCITIES:	VXO	VYO	VZO
ADJUSTED VALUES	99.055	98.709	2000.998
RESIDUALS	10.459	0.764	0.646
RATE OF CHANGE OF ROTATIONS:	D(OMEGA)	D(PHI)	D(KAPPA)
ADJUSTED VALUES	-0.424	-0.134	0.909
RESIDUALS	0.042	0.058	-0.410

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1			
ADJUSTED VALUES	1823681.749	159598.339	88906.929
RESIDUALS	-53423.967	3030.825	-18726.347
POINT NO. 2			
ADJUSTED VALUES	1704737.260	156422.423	361988.766
RESIDUALS	-1641.150	-17085.943	-7477.138

APPENDIX III

REAL DATA ADJUSTMENT RESULTS

THE INITIAL APPROXIMATIONS

PHOTO NO. 97

XO	YO	ZO
1067571.800	878419.200	4220801.100
KAPPA(RAD)	PHI(RAD)	OMEGA(RAD)
-1.776614	-0.103605	-1.318480

PHOTO NO. 102

XO	YO	ZO
1065711.800	385539.900	4288146.900
KAPPA(RAD)	PHI(RAD)	OMEGA(RAD)
-1.655726	-0.093986	-1.317074

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1160	107337.840	140515.010	1726644.673
POINT NO. 1161	125094.925	146305.068	1729429.218
POINT NO. 1162	156876.521	173293.439	1722151.275
POINT NO. 1163	111501.158	157326.494	1726872.028
POINT NO. 1165	47875.606	174323.832	1730285.854
POINT NO. 1166	20227.076	177837.323	1729918.469
POINT NO. 1167	26464.591	187210.435	1729313.778
POINT NO. 1169	83048.920	190473.316	1729436.703
POINT NO. 1170	90684.547	186472.323	1723198.309
POINT NO. 1171	92042.052	196008.361	1725997.290
POINT NO. 1173	132427.310	189588.804	1725402.894
POINT NO. 2033	588692.487	180056.655	1626234.137
POINT NO. 2034	398289.340	205973.820	1679831.473
POINT NO. 2036	230591.051	152520.024	1717161.301
POINT NO. 2038	52971.883	157248.728	1731490.453

ITERATION NO. 1

PHOTO NO. 97

	XO	YO	ZO
ADJUSTED VALUES	1067508.578	878400.953	4220687.177
CORRECTIONS	-63.222	-18.247	-113.923

	KAPPA(DEG)	PHI(DEG)	OMEGA(DEG)
ADJUSTED VALUES	-101.125777	5.032040	-54.622742
CORRECTIONS	0.666723	10.968151	20.920591

PHOTO NO. 102

	XO	YO	ZO
ADJUSTED VALUES	1065652.835	385528.396	4287995.852
CORRECTIONS	-58.965	-11.504	-151.048

	KAPPA(DEG)	PHI(DEG)	OMEGA(DEG)
ADJUSTED VALUES	-93.568087	-2.747624	-59.690898
CORRECTIONS	1.298024	2.637376	15.771879

	X-COORD	Y-COORD	Z-COORD
POINT NO. 1160			
ADJUSTED VALUES	117109.535	113198.107	1723423.432
CORRECTIONS	9771.695	-27316.903	-3221.241
POINT NO. 1161			
ADJUSTED VALUES	134806.070	123127.012	1726708.042
CORRECTIONS	9711.145	-23178.056	-2721.176
POINT NO. 1162			
ADJUSTED VALUES	159839.845	171379.216	1722181.588
CORRECTIONS	2963.324	-1914.223	30.313
POINT NO. 1163			
ADJUSTED VALUES	116071.773	143804.151	1725459.871
CORRECTIONS	4570.615	-13522.343	-1412.157

POINT NO. 1165			
ADJUSTED VALUES	40501.468	177575.677	1732140.973
CORRECTIONS	-7374.138	3251.845	1855.119
POINT NO. 1166			
ADJUSTED VALUES	9210.815	185427.337	1732605.213
CORRECTIONS	-11016.261	7590.014	2686.744
POINT NO. 1167			
ADJUSTED VALUES	12788.702	202570.658	1733380.405
CORRECTIONS	-13675.889	15360.223	4066.627
POINT NO. 1169			
ADJUSTED VALUES	74000.821	205863.579	1733279.995
CORRECTIONS	-9048.099	15390.263	3843.292
POINT NO. 1170			
ADJUSTED VALUES	83588.173	198298.003	1725964.392
CORRECTIONS	-7096.374	11825.680	2766.083
POINT NO. 1171			
ADJUSTED VALUES	82145.220	215822.268	1730458.143
CORRECTIONS	-9896.832	19813.907	4460.853
POINT NO. 1173			
ADJUSTED VALUES	128438.824	202209.069	1728139.839
CORRECTIONS	-3988.486	12620.265	2736.945
POINT NO. 2033			
ADJUSTED VALUES	605911.486	175898.281	1620929.739
CORRECTIONS	17218.999	-4158.374	-5304.398
POINT NO. 2034			
ADJUSTED VALUES	404468.893	223378.958	1680614.903
CORRECTIONS	6179.553	17405.138	783.430
POINT NO. 2036			
ADJUSTED VALUES	246401.018	131519.247	1713694.423
CORRECTIONS	15809.967	-21000.777	-3466.878
POINT NO. 2038			
ADJUSTED VALUES	51897.362	145825.846	1731011.191
CORRECTIONS	-1074.521	-11422.882	-479.262

ITERATICN NO. 8

PHCTC NO. 97

	XO	YC	ZC
ADJUSTED VALUES	1067570.840	878421.585	4220800.311
CORRECTIONS	0.000	0.000	0.000

	KAPPA(DEG)	PHI(DEG)	OMEGA(DEG)
ADJUSTED VALUES	-173.731565	14.389261	-13.287869
CORRECTIONS	0.000013	0.000001	0.000001

PHOTO NO. 102

	XO	YO	ZC
ADJUSTED VALUES	1065710.979	385542.734	4288146.274
CORRECTIONS	0.005	-0.000	-0.001

	KAPPA(CEG)	PHI(DEG)	OMEGA(DEG)
ADJUSTED VALUES	-174.284091	14.475044	-6.223241
CORRECTIONS	0.000006	0.000001	0.000007

	X-COORD	Y-COORD	Z-CCORD
POINT NO. 1160			
ADJUSTED VALUES	106993.774	140393.578	1726801.221
CORRECTIONS	-0.011	0.039	0.001
POINT NO. 1161			
ADJUSTED VALUES	125284.750	146302.815	1729351.293
CORRECTIONS	-0.000	-0.017	0.002
PCINT NO. 1162			
ADJUSTED VALUES	156806.878	173401.091	1722157.185
CORRECTIONS	-0.005	0.014	0.001
POINT NO. 1163			
ADJUSTED VALUES	111531.199	157206.440	1726882.596
CORRECTIONS	-0.006	-0.001	0.003

POINT NO. 1165			
ADJUSTED VALUES	47863.804	174409.061	1730267.883
CORRECTIONS	0.005	-0.004	-0.001
POINT NO. 1166			
ADJUSTED VALUES	20204.412	177377.089	1730012.769
CORRECTIONS	-0.007	-0.030	0.005
POINT NO. 1167			
ADJUSTED VALUES	26385.335	187168.704	1729366.306
CORRECTIONS	0.008	-0.004	-0.003
POINT NO. 1169			
ADJUSTED VALUES	83146.759	190680.690	1729352.337
CORRECTIONS	0.007	-0.013	-0.001
POINT NO. 1170			
ADJUSTED VALUES	90315.774	186120.034	1723407.927
CORRECTIONS	-0.022	0.022	0.007
POINT NO. 1171			
ADJUSTED VALUES	92006.760	195937.706	1726027.442
CORRECTIONS	-0.001	-0.013	0.001
POINT NO. 1173			
ADJUSTED VALUES	132777.824	189464.364	1725282.066
CORRECTIONS	-0.006	-0.044	0.004
POINT NO. 2033			
ADJUSTED VALUES	588751.698	180399.692	1626167.075
CORRECTIONS	-0.051	0.043	0.002
POINT NO. 2034			
ADJUSTED VALUES	398310.801	206235.838	1679787.833
CORRECTIONS	-0.027	0.022	0.003
POINT NO. 2036			
ADJUSTED VALUES	230672.200	152669.546	1717108.511
CORRECTIONS	-0.006	0.006	0.001
POINT NO. 2038			
ADJUSTED VALUES	53117.856	157256.502	1731430.783
CORRECTIONS	0.009	-0.018	-0.001